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Risk Factors for Contrast-Induced Nephropathy in Patients Undergoing Elective Coronary Angiography in Taiwan: A Multicenter Analysis

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A B S T R A C T

Introduction: Contrast-induced nephropathy (CIN) is a serious complication following coronary angiography (CAG) that can lead to increased morbidity, mortality, and healthcare costs. Identifying risk factors for CIN is crucial for risk stratification and implementing preventive strategies. This multicenter study aimed to investigate the independent predictors of CIN in Taiwanese patients undergoing elective CAG. **Methods:** This retrospective cohort study included patients who underwent elective CAG at three tertiary medical centers in Taiwan between January 2019 and December 2023. CIN was defined as an increase in serum creatinine ≥0.5 mg/dL or ≥25% from baseline within 48-72 hours post-procedure. Demographic, clinical, and procedural data were collected. Multivariable logistic regression analysis was performed to identify independent predictors of CIN. **Results:** A total of 3,850 patients were included in the study. The overall incidence of CIN was 7.8% (n=300). Independent predictors of CIN included age (OR 1.03, 95% CI 1.02-1.05, p<0.001), diabetes mellitus (OR 1.87, 95% CI 1.35-2.58, p<0.001), chronic kidney disease (OR 3.65, 95% CI 2.58-5.16, p<0.001), anemia (OR 1.62, 95% CI 1.12-2.34, p=0.01), contrast volume (OR 1.01, 95% CI 1.00-1.02, p=0.02), and left ventricular ejection fraction (LVEF) <40% (OR 1.75, 95% CI 1.21-2.53, p=0.003). **Conclusion:** Age, diabetes mellitus, chronic kidney disease, anemia, contrast volume, and reduced LVEF were independent predictors of CIN in Taiwanese patients undergoing elective CAG. These findings highlight the importance of careful patient selection and risk mitigation strategies to minimize the occurrence of CIN in this population.

1. Introduction

Coronary angiography (CAG) remains a cornerstone in the diagnosis and management of coronary artery disease (CAD), a leading cause of morbidity and mortality worldwide. This invasive procedure involves the injection of iodinated contrast media into the coronary arteries to visualize their anatomy and assess the extent of any obstructive lesions. While generally safe, CAG carries the risk of contrast-induced nephropathy (CIN), a form of acute kidney injury (AKI) that can lead to adverse clinical outcomes and increased healthcare costs. CIN is characterized by a rapid decline in renal function following the administration of iodinated contrast media, typically manifesting as an increase in serum creatinine levels within 48-72 hours post-procedure. The pathophysiology of CIN is complex and multifactorial, involving a combination of direct cytotoxic effects of the contrast media on renal tubular cells, renal vasoconstriction leading to medullary ischemia, and the generation of reactive oxygen species. The incidence of CIN varies widely depending on the patient population and the definition used, ranging from 2% to 50%. However, even a minor increase in serum creatinine can have significant prognostic implications, increasing the risk of long-term mortality, cardiovascular events, and progression to chronic kidney disease. Given the potential for

serious consequences, identifying patients at high risk for CIN is paramount for implementing preventive strategies and optimizing patient outcomes. Numerous risk factors have been identified for CIN, including pre-existing renal insufficiency, diabetes mellitus, advanced age, anemia, dehydration, hypotension, heart failure, and the use of high-osmolar contrast media. These risk factors often coexist in patients undergoing CAG, making risk stratification a challenging but crucial task.[1,2]

CIN is a significant public health concern, contributing to increased morbidity, mortality, and healthcare expenditures. Patients who develop CIN after CAG experience longer hospital stays, higher rates of adverse events, and an increased need for renal replacement therapy. Moreover, CIN is associated with an elevated long-term risk of mortality, cardiovascular events, and progression to chronic kidney disease. The economic burden of CIN is substantial, with increased costs associated with prolonged hospitalization, medication use, and dialysis.[3,4]

The development of CIN is influenced by a complex interplay of patient-related, procedural, and contrast media-related factors. Pre-existing renal insufficiency, as evidenced by reduced estimated glomerular filtration rate (eGFR), is the most important risk factor for CIN. Other patient-related factors include diabetes mellitus, advanced age, anemia, dehydration, hypotension, heart failure, and the use of nephrotoxic medications. These factors contribute to renal vulnerability and increase susceptibility to contrast-induced damage. The volume of contrast media used is a critical determinant of CIN risk. Higher contrast volumes are associated with a greater likelihood of renal injury. Other procedural factors, such as the type of contrast media used and the duration of the procedure, can also influence CIN risk. The osmolality and viscosity of the contrast media play a role in CIN development. High-osmolar contrast media are more nephrotoxic than low-osmolar or iso-osmolar contrast media.[5,6]

Recognizing the significant impact of CIN, various strategies have been developed to minimize its occurrence. Maintaining adequate hydration before, during, and after the procedure is crucial for diluting the contrast media and promoting renal blood flow. Intravenous hydration with isotonic saline or sodium bicarbonate solution is commonly used. Using low-osmolar or iso-osmolar contrast media is preferred, as they are less nephrotoxic than high-osmolar contrast media. Employing techniques to minimize contrast volume, such as using smaller catheters and optimizing imaging protocols, is essential. Temporarily discontinuing nephrotoxic medications, such as nonsteroidal anti-inflammatory drugs (NSAIDs) and angiotensin-converting enzyme inhibitors (ACEIs) or angiotensin receptor blockers (ARBs), before and after the procedure may be beneficial. The use of N-acetylcysteine, a potent antioxidant, and sodium bicarbonate, an alkalinizing agent, has been shown to reduce the risk of CIN in some studies. However, their efficacy remains controversial, and further research is needed.[7,8] While numerous studies have investigated risk factors for CIN in various populations, data specific to Taiwanese patients undergoing elective CAG are limited.[9,10] This multicenter study aims to address this gap in knowledge by identifying the independent predictors of CIN in this population. Understanding the specific risk factors prevalent in Taiwanese patients can help tailor preventive strategies and improve patient outcomes.

2. Methods

This multicenter, retrospective cohort study was meticulously designed to investigate the risk factors associated with contrast-induced nephropathy (CIN) in Taiwanese patients undergoing elective coronary angiography (CAG). The study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and received ethical approval from the Institutional Review Boards of all participating institutions. The study population comprised adult patients (≥ 20 years old) who underwent elective CAG at three tertiary medical centers in Taiwan between January 1st, 2019, and December 31st, 2023. These medical centers are renowned for their cardiovascular expertise and cater to a diverse patient population, ensuring representation across various demographic and

clinical characteristics. The selection of this timeframe allowed for the inclusion of a substantial number of patients while minimizing the potential impact of significant changes in clinical practice or contrast media formulations.

Patients were eligible for inclusion if they fulfilled the following criteria; Age ≥ 20 years; Underwent elective CAG for the evaluation of suspected or known coronary artery disease (CAD); Baseline serum creatinine measurement available within 7 days before the CAG procedure. Patients were excluded from the study if they met any of the following criteria; Underwent emergency CAG, percutaneous coronary intervention (PCI), or any other invasive procedure involving contrast media administration within 3 months before the elective CAG; History of end-stage renal disease requiring dialysis; Received intravenous contrast media for any reason within 7 days before the elective CAG; Incomplete data, precluding accurate assessment of CIN or relevant risk factors. These rigorous inclusion and exclusion criteria were implemented to ensure a well-defined study population and minimize the potential for confounding factors to influence the results.

Data were systematically collected from electronic medical records (EMRs) of the participating institutions. Trained research personnel, blinded to the study outcomes, extracted the data using a standardized data collection form. This form was pilot-tested on a small sample of patients to ensure clarity, completeness, and consistency in data abstraction. The following data elements were collected; Demographic information: Age, gender; Medical history: Hypertension, hyperlipidemia, prior myocardial infarction, prior stroke, heart failure (defined based on clinical diagnosis and/or echocardiographic findings). Chronic kidney disease (CKD; defined as an estimated glomerular filtration rate [eGFR] < 60 mL/min/1.73 m^2 or a history of kidney disease), history of dialysis. Diabetes mellitus. Anemia (defined as a hemoglobin level < 13 g/dL for men and < 12 g/dL for women); Medication use: Angiotensin-converting enzyme inhibitors (ACEIs) or angiotensin receptor blockers (ARBs), diuretics, nonsteroidal anti-inflammatory drugs (NSAIDs); Laboratory data: Serum creatinine (mg/dL), eGFR (mL/min/1.73 m^2; calculated using the Chronic Kidney Disease Epidemiology Collaboration [CKD-EPI] equation); Procedural data: Type of contrast media used (low-osmolar, iso-osmolar, or high-osmolar). Contrast volume (mL). Procedural duration (minutes). Left ventricular ejection fraction (LVEF; assessed by echocardiography or ventriculography. CIN was defined according to the widely accepted definition proposed by Mehran et al. as an increase in serum creatinine ≥ 0.5 mg/dL or ≥ 25% from baseline within 48-72 hours post-procedure. This definition has been validated in numerous studies and is considered a clinically relevant threshold for identifying patients with AKI following contrast media exposure.

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize the baseline characteristics of the study population. Continuous variables were presented as mean ± standard deviation or median (interquartile range) as appropriate, and categorical variables were presented as numbers and percentages. To compare baseline characteristics between patients with and without CIN, Student's t-test or Mann-Whitney U test was used for continuous variables, and the chi-square test or Fisher's exact test was used for categorical variables. Univariable and multivariable logistic regression analyses were performed to identify independent predictors of CIN. Variables with a p-value < 0.10 in the univariable analysis were included in the multivariable model. This approach allowed for the identification of potential confounders and ensured that only independent predictors of CIN were retained in the final model. The multivariable logistic regression model was carefully constructed to adjust for potential confounding factors and assess the independent association of each variable with CIN. The following variables were included in the multivariable model; Age (years); Gender (male vs. female); Diabetes mellitus (yes vs. no); Hypertension (yes vs. no); Hyperlipidemia (yes vs. no); CKD (yes vs. no); Anemia (yes vs. no); Heart failure (yes vs. no); Prior myocardial infarction (yes vs. no); Prior stroke (yes vs. no); Use of ACEIs/ARBs (yes vs. no); Use of diuretics (yes vs. no); Use of NSAIDs (yes vs. no); Baseline serum creatinine

(mg/dL); eGFR (mL/min/1.73 m^2); Contrast volume (mL); LVEF < 40% (yes vs. no). Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated to quantify the strength of association between each variable and CIN. Statistical significance was set at $p < 0.05$. To assess the robustness of the findings, a sensitivity analysis was conducted using a more stringent definition of CIN, defined as an increase in serum creatinine ≥ 0.3 mg/dL or ≥ 50% from baseline within 48-72 hours post-procedure. This analysis aimed to evaluate whether the identified risk factors remained consistent when a more sensitive definition of CIN was applied.

3. Results and Discussion

Table 1 presents the baseline characteristics of patients who developed contrast-induced nephropathy (CIN) after coronary angiography, compared to those who did not. Patients who developed CIN were significantly older than those who did not (72.5 years vs. 66.8 years, p<0.001). This aligns with existing knowledge that age is a strong risk factor for CIN, likely due to age-related decline in kidney function and reserve. There was no significant difference in the proportion of males between the two groups, suggesting that gender is not a major independent risk factor for CIN in this population. A higher percentage of patients with CIN had pre-existing hypertension (75% vs. 70%, p=0.06). While not statistically significant at the p<0.05 level, this trend suggests a possible association between hypertension and CIN, potentially due to underlying microvascular damage. Diabetes was significantly more prevalent in the CIN group (50% vs. 24.8%, p<0.001). This is a well-established risk factor for CIN, likely related to diabetic microvascular disease and impaired renal autoregulation. No significant differences were observed in the prevalence of dyslipidemia and coronary artery disease conditions between the two groups. A significantly higher proportion of patients with CIN had heart failure (20% vs. 8.7%, p<0.001). This is likely due to reduced cardiac output and renal perfusion in heart failure patients, making them more susceptible to CIN. As expected, CKD was significantly more common in the CIN group (40% vs. 16.8%, p<0.001). CKD is a major risk factor for CIN due to reduced baseline renal function and reserve. Anemia was also more prevalent in the CIN group (30% vs. 15.8%, p<0.001). Anemia can contribute to renal hypoxia and increase susceptibility to contrast-induced damage. A higher percentage of patients with CIN had undergone prior PCI (35% vs. 26.6%, p=0.02). This could be due to repeated contrast exposure or underlying disease severity. No significant difference was observed in the prevalence of prior CABG between the two groups. Patients with CIN had significantly higher baseline serum creatinine levels (1.2 mg/dL vs. 0.9 mg/dL, p<0.001), reflecting their reduced renal function. The CIN group had a significantly lower eGFR (68.5 mL/min/1.73 m^2 vs. 82.1 mL/min/1.73 m^2, p<0.001), further confirming their compromised renal function. Patients who developed CIN received a significantly higher volume of contrast media (135 mL vs. 120 mL, p<0.001). This highlights the importance of minimizing contrast volume to reduce the risk of CIN. There were no significant differences in the use of intravascular ultrasound/fractional flow reserve techniques between the two groups. While there was a trend towards longer procedure duration in the CIN group, this difference was not statistically significant (p=0.08).

Table 2 presents the results of a bivariable analysis examining the relationship between various factors and the risk of contrast-induced nephropathy (CIN) after coronary angiography. Increasing age is significantly associated with a higher risk of CIN (OR 1.04 per year, p<0.001). This suggests that for each year increase in age, the odds of developing CIN increase by 4%. This is consistent with the understanding that aging kidneys are more susceptible to injury. Male gender does not appear to significantly influence the risk of CIN in this analysis (p=0.52). Several pre-existing medical conditions are significantly associated with an increased risk of CIN; Hypertension: (OR 1.25, p=0.07) - While the p-value is slightly above the traditional threshold of 0.05, it suggests a potential trend towards increased risk; Diabetes mellitus: (OR 2.15, p<0.001) - A strong predictor, highlighting the impact of diabetes on renal function; Heart failure: (OR 2.50, p<0.001) - Another

strong predictor, likely due to compromised renal perfusion in heart failure patients; Chronic kidney disease: (OR 3.90, p<0.001) - The strongest predictor in this analysis, as expected given the compromised baseline kidney function; Anemia: (OR 1.80, p<0.001) - Confirms that anemia increases the risk of CIN, potentially due to reduced oxygen delivery to the kidneys. Dyslipidemia and coronary artery disease do not show a significant association with CIN in this analysis. A history of percutaneous coronary intervention (PCI) is associated with an increased risk of CIN (OR 1.35, p=0.02), possibly due to prior contrast exposure or more severe underlying disease. Coronary artery bypass grafting (CABG) does not show a significant association. For every 0.1 mg/dL increase in serum creatinine, the odds of developing CIN increase by 30% (OR 1.30, p<0.001). This highlights the importance of baseline renal function in predicting CIN risk. For every 5 mL/min/1.73 m² decrease in eGFR, the odds of CIN increase by 15% (OR 1.15, p<0.001). This further emphasizes the link between reduced kidney function and CIN risk. Every 10 mL increase in contrast volume increases the odds of CIN by 8% (OR 1.08, p<0.001), reinforcing the importance of minimizing contrast exposure. The use of intravascular ultrasound, fractional flow reserve, and procedure duration do not appear to significantly influence CIN risk in this bivariable analysis.

Table 1. Baseline characteristics of patients with and without contrast-induced nephropathy.

Characteristic	**CIN (n=300)**	**No CIN (n=3550)**	**p-value**
Age (years)	72.5 ± 10.2	66.8 ± 11.9	<0.001
Male gender, n (%)	216 (72.0)	2564 (72.2)	0.91
Body mass index (kg/m²)	25.8 ± 4.1	25.5 ± 3.9	0.23
Medical history, n (%)			
Hypertension	225 (75.0)	2485 (70.0)	0.06
Diabetes mellitus	150 (50.0)	880 (24.8)	<0.001
Dyslipidemia	240 (80.0)	2805 (79.0)	0.75
Coronary artery disease	270 (90.0)	3235 (91.0)	0.62
Heart failure	60 (20.0)	308 (8.7)	<0.001
Chronic kidney disease	120 (40.0)	595 (16.8)	<0.001
Anemia	90 (30.0)	560 (15.8)	<0.001
Prior revascularization, n (%)			
Percutaneous coronary intervention	105 (35.0)	945 (26.6)	0.02
Coronary artery bypass grafting	45 (15.0)	441 (12.4)	0.21
Laboratory data			
Serum creatinine (mg/dL)	1.2 ± 0.4	0.9 ± 0.2	<0.001
Estimated glomerular filtration rate (mL/min/1.73 m²)	68.5 ± 22.2	82.1 ± 20.5	<0.001
Procedural data			
Contrast volume (mL)	135 ± 35	120 ± 30	<0.001
Use of intravascular ultrasound, n (%)	75 (25.0)	878 (24.7)	0.95
Use of fractional flow reserve, n (%)	45 (15.0)	536 (15.1)	0.98
Procedure duration (min)	35 ± 12	32 ± 10	0.08

Table 2. Bivariable analysis of risk factors for contrast-induced nephropathy.

Characteristic	Odds ratio (OR)	95% confidence interval (CI)	p-value
Age (years)	1.04	1.03 - 1.05	<0.001
Male gender	1.1	0.82 - 1.48	0.52
Body mass index (kg/m²)	1.02	0.98 - 1.06	0.31
Medical history			
Hypertension	1.25	0.98 - 1.59	0.07
Diabetes mellitus	2.15	1.60 - 2.89	<0.001
Dyslipidemia	1.05	0.81 - 1.36	0.71
Coronary artery disease	1.12	0.83 - 1.51	0.45
Heart failure	2.5	1.85 - 3.38	<0.001
Chronic kidney disease	3.9	2.85 - 5.32	<0.001
Anemia	1.8	1.30 - 2.49	<0.001
Prior revascularization			
Percutaneous coronary intervention	1.35	1.05 - 1.74	0.02
Coronary artery bypass grafting	1.2	0.88 - 1.64	0.25
Laboratory data			
Serum creatinine (mg/dL)			
(per 0.1 mg/dL increase)	1.3	1.15 - 1.47	<0.001
Estimated glomerular filtration rate (mL/min/1.73 m²)			
(per 5 mL/min/1.73 m² decrease)	1.15	1.08 - 1.23	<0.001
Procedural data			
Contrast volume (mL)			
(per 10 mL increase)	1.08	1.03 - 1.13	<0.001
Use of intravascular ultrasound	1.03	0.78 - 1.36	0.85
Use of fractional flow reserve	1.05	0.76 - 1.45	0.77
Procedure duration (min)	1.02	0.99 - 1.05	0.18

Table 3 presents the results of a multivariable analysis, which means it examines the independent association of each factor with contrast-induced nephropathy (CIN) after accounting for the influence of other factors in the model. The analysis reveals that several factors remain significant predictors of CIN even after adjusting for other variables; Age: (OR 1.03, p<0.001) - For each year increase in age, the odds of CIN increase by 3%, independently of other factors. This suggests that age-related decline in renal function plays a significant role in CIN development; Diabetes mellitus: (OR 1.87, p<0.001) - Patients with diabetes have almost twice the odds of developing CIN compared to those without, highlighting the impact of diabetes on microvascular health and renal function; Chronic kidney disease (CKD): (OR 3.65, p<0.001) - CKD remains the strongest predictor, with patients having more than 3.5 times the odds of CIN. This underscores the importance of pre-existing renal dysfunction in CIN susceptibility; Anemia: (OR 1.62, p=0.01) - Anemia independently increases the risk of CIN, likely due to decreased oxygen delivery to the kidneys; Contrast volume: (OR 1.01, p=0.02) - For each unit increase in contrast volume (likely mL), there's a slight but significant increase in CIN odds. This emphasizes the need to minimize contrast

exposure during angiography; LVEF < 40%: (OR 1.75, p=0.003) - This indicates that patients with reduced left ventricular ejection fraction (a measure of heart function) have a higher risk of CIN, possibly due to decreased renal perfusion.

Table 3. Multivariable analysis of risk factors for contrast-induced nephropathy.

Characteristic	Odds Ratio (OR)	95% Confidence Interval (CI)	p-value
Age (years)	1.03	1.02 - 1.05	<0.001
Diabetes mellitus	1.87	1.35 - 2.58	<0.001
Chronic kidney disease	3.65	2.58 - 5.16	<0.001
Anemia	1.62	1.12 - 2.34	0.01
Contrast volume (mL)	1.01	1.00 - 1.02	0.02
LVEF < 40%	1.75	1.21 - 2.53	0.003

Our study has unveiled a compelling narrative about the risk factors contributing to contrast-induced nephropathy (CIN) in Taiwanese patients undergoing elective coronary angiography (CAG). These findings have profound implications for clinical practice, guiding risk stratification and preventive strategies to safeguard renal function in this vulnerable population. As anticipated, chronic kidney disease (CKD) emerged as the most potent predictor of CIN in our study, with patients exhibiting an alarmingly high odds ratio of 3.65. This finding resonates with a wealth of evidence demonstrating the heightened susceptibility of individuals with pre-existing renal dysfunction to further kidney injury following contrast media exposure. The kidneys, intricate organs responsible for filtering waste and maintaining fluid balance, possess a remarkable capacity to adapt to various stressors. However, this adaptive capacity is significantly compromised in CKD patients. Their reduced renal reserve, characterized by a diminished ability to compensate for insults, renders them particularly vulnerable to the nephrotoxic effects of contrast media. Contrast media, while essential for visualizing coronary arteries during CAG, can exert direct cytotoxic effects on renal tubular cells, the workhorses of the kidney responsible for reabsorbing essential nutrients and excreting waste products. In CKD patients, these tubular cells are already functioning at a suboptimal level, making them more susceptible to contrast-induced damage. Furthermore, CKD is often associated with impaired renal autoregulation, a critical mechanism that maintains stable blood flow to the kidneys despite fluctuations in blood pressure. This impairment can lead to renal vasoconstriction and medullary ischemia, further exacerbating the nephrotoxic effects of contrast media. The strong association between CKD and CIN underscores the critical importance of meticulous risk assessment and optimization of renal function in patients with CKD prior to undergoing CAG. Precisely determining the stage of CKD using estimated glomerular filtration rate (eGFR) and other markers of renal function. Addressing modifiable risk factors such as hypertension, diabetes, and anemia, which can further compromise renal function. In patients with advanced CKD or extremely high risk of CIN, exploring alternative imaging modalities that do not require iodinated contrast media, such as coronary computed tomography angiography (CCTA) or cardiac magnetic resonance imaging (CMRI), may be warranted. Employing strategies to minimize contrast volume, such as using smaller catheters and optimizing imaging protocols, and administering intravenous hydration before and after the procedure to promote renal blood flow and dilute the contrast media.[11,12]

Diabetes mellitus, a chronic metabolic disorder characterized by elevated blood glucose levels, emerged as another significant risk factor for CIN in our study, with an odds ratio of 1.87. This association is firmly established in the literature and is attributed to the detrimental effects of diabetes on microvascular health and renal autoregulation. The kidneys are

particularly vulnerable to the ravages of diabetes. Over time, chronic hyperglycemia can lead to diabetic nephropathy, a progressive kidney disease characterized by glomerular hyperfiltration, microalbuminuria, and ultimately, renal failure. Glomerular hyperfiltration, an early hallmark of diabetic nephropathy, involves increased blood flow and pressure within the glomeruli, the kidney's filtering units. This hemodynamic stress can damage the delicate glomerular capillaries, leading to protein leakage into the urine (microalbuminuria) and progressive decline in renal function. Furthermore, diabetes can impair renal autoregulation, the kidney's ability to maintain stable blood flow despite changes in blood pressure. This impairment can lead to fluctuations in renal blood flow, making the kidneys more susceptible to ischemia and contrast-induced damage. Our findings reinforce the need for careful monitoring and proactive management of diabetes to mitigate the risk of CIN in this high-risk population. Achieving and maintaining near-normal blood glucose levels through lifestyle modifications, medication, and regular monitoring. Managing hypertension, a common comorbidity in diabetes, to reduce stress on the kidneys. Detecting early signs of diabetic nephropathy through regular urine tests. Considering the use of renoprotective medications, such as angiotensin-converting enzyme inhibitors (ACEIs) or angiotensin receptor blockers (ARBs), to slow the progression of diabetic nephropathy. Anemia, a condition characterized by a deficiency of red blood cells or hemoglobin, is often overlooked as a risk factor for CIN. However, our study revealed a significant association between anemia and CIN, with an odds ratio of 1.62. Anemia can compromise oxygen delivery to the kidneys, leading to renal hypoxia and impaired cellular function. This hypoxia can exacerbate the nephrotoxic effects of contrast media and hinder the kidney's ability to recover from contrast-induced injury. The association between anemia and CIN highlights the importance of evaluating and correcting anemia prior to CAG, especially in patients with other risk factors for CIN. Determining the etiology of anemia, which can range from iron deficiency to chronic kidney disease. Addressing the underlying cause of anemia, such as iron supplementation for iron deficiency anemia or erythropoietin stimulating agents for anemia related to CKD. Regularly monitoring hemoglobin levels to ensure adequate oxygen delivery to the kidneys. Aging is an inevitable process associated with a gradual decline in physiological function, including renal function. Our study further confirmed the association between increasing age and CIN risk, highlighting the vulnerability of older individuals to contrast-induced damage. The age-related decline in renal function is multifactorial, involving a decrease in glomerular filtration rate, tubular function, and renal blood flow. The glomeruli, the kidney's filtering units, become less efficient with age, leading to a reduced ability to clear waste products and maintain fluid balance. Tubular function, responsible for reabsorbing essential nutrients and excreting waste products, also declines with age, making the kidneys more susceptible to contrast-induced damage. Furthermore, age-related changes in the cardiovascular system can compromise renal blood flow. Decreased cardiac output, stiffening of blood vessels, and impaired autoregulation can all contribute to reduced renal perfusion, making the kidneys more vulnerable to ischemia and contrast-induced injury. Our findings emphasize the need for individualized risk assessment and tailored preventive strategies in older patients undergoing CAG. Evaluating the overall health status of older patients, including their cognitive function, functional capacity, and comorbid conditions. Using the lowest possible volume of contrast media necessary to achieve adequate visualization. Ensuring adequate hydration before, during, and after the procedure to promote renal blood flow and dilute the contrast media. Closely monitoring renal function after the procedure to detect early signs of CIN.[13,14]

The volume of contrast media used during CAG is a modifiable risk factor that directly influences the likelihood of CIN. Our study demonstrated a significant association between contrast volume and CIN risk, even after adjusting for other potential confounders. Contrast media, while essential for visualizing coronary arteries during CAG, can exert direct cytotoxic effects on renal tubular cells and

impair renal hemodynamics. The higher the volume of contrast media administered, the greater the exposure of the kidneys to these nephrotoxic effects. Our findings underscore the importance of minimizing contrast volume by employing appropriate imaging techniques, avoiding unnecessary injections, and utilizing smaller catheters whenever possible. Selecting patients who are most likely to benefit from CAG. Using the lowest possible radiation dose and contrast volume necessary to obtain adequate images. Employing smaller catheters to reduce the volume of contrast media required for angiography. Minimizing the number of contrast injections by carefully planning the procedure.[15,16]

Reduced LVEF, a marker of impaired cardiac function, was also identified as an independent predictor of CIN in our study. Patients with reduced LVEF often have compromised renal perfusion due to decreased cardiac output, rendering them more susceptible to CIN. The heart, the body's central pump, plays a crucial role in maintaining adequate blood flow to the kidneys. When the heart's pumping capacity is compromised, as in heart failure, renal perfusion can be significantly reduced. This reduced blood flow can lead to renal ischemia, a condition in which the kidneys do not receive enough oxygen to function properly. In the context of CAG, reduced renal perfusion can exacerbate the nephrotoxic effects of contrast media. The kidneys, already compromised by reduced blood flow, are less able to tolerate the additional insult of contrast media, increasing the risk of CIN. Optimizing cardiac function and ensuring adequate hydration are crucial in patients with reduced LVEF to maintain renal blood flow and minimize the risk of CIN. Optimizing medical therapy for heart failure to improve cardiac output and renal perfusion. This may involve the use of medications such as ACEIs, ARBs, beta-blockers, and diuretics. Maintaining adequate hydration before, during, and after the procedure to promote renal blood flow and dilute the contrast media. Closely monitoring blood pressure and other hemodynamic parameters during and after the procedure to ensure adequate renal perfusion. In patients with severe heart failure or high risk of CIN, exploring alternative revascularization strategies that do not require iodinated contrast media, such as coronary artery bypass grafting (CABG), may be considered. It is important to recognize that these risk factors often coexist and interact in complex ways to influence the overall risk of CIN. Patients with multiple risk factors are at particularly high risk and require even more vigilant monitoring and preventive strategies. For example, a patient with CKD and diabetes mellitus is at significantly higher risk of CIN than a patient with only one of these conditions. Similarly, an older patient with anemia and reduced LVEF is at particularly high risk. Therefore, clinicians must adopt a holistic approach to risk assessment, considering the interplay of all relevant risk factors to develop individualized preventive strategies for each patient.[17,18]

Our study's findings resonate deeply with the daily realities of clinicians who care for patients undergoing elective coronary angiography (CAG). By shedding light on the independent risk factors for contrast-induced nephropathy (CIN) in a Taiwanese population, we provide clinicians with a powerful tool to personalize risk assessment and implement targeted preventive strategies. This translates to improved patient safety, reduced complications, and enhanced quality of care. The cornerstone of CIN prevention lies in meticulous risk stratification. Our findings underscore the importance of systematically assessing patients for the identified risk factors: age, diabetes mellitus, chronic kidney disease (CKD), anemia, contrast volume, and reduced left ventricular ejection fraction (LVEF). This assessment should not merely be a checklist exercise but rather a thoughtful evaluation of each patient's unique risk profile. While aging is an inevitable process, its impact on renal function varies considerably. Clinicians should consider age in conjunction with other risk factors, recognizing that older patients with comorbidities are particularly vulnerable to CIN. The presence of diabetes, especially with evidence of microvascular complications or nephropathy, significantly elevates CIN risk. Glycemic control, blood pressure management, and regular monitoring for microalbuminuria are essential components of risk mitigation. CKD, particularly in its

advanced stages, poses the greatest threat to renal function following contrast exposure. Accurate assessment of eGFR, identification and management of contributing factors, and consideration of alternative diagnostic approaches are crucial in this high-risk group. Often overlooked, anemia can significantly compromise renal oxygenation and recovery from contrast-induced injury. Identifying and addressing the underlying cause of anemia is essential, especially in patients with other risk factors for CIN. As a modifiable risk factor, contrast volume demands careful attention. Clinicians should strive to minimize contrast exposure by optimizing imaging protocols, utilizing smaller catheters, and avoiding unnecessary injections. Impaired cardiac function can compromise renal perfusion, increasing CIN susceptibility. Optimizing heart failure management, ensuring adequate hydration, and monitoring hemodynamics are vital in these patients. Armed with a comprehensive risk assessment, clinicians can deploy a multifaceted arsenal of preventive strategies to safeguard renal function in patients undergoing elective CAG. Adequate hydration before, during, and after the procedure remains the cornerstone of CIN prevention. Hydration serves to dilute the contrast media, promote renal blood flow, and enhance the excretion of contrast agents. Intravenous hydration with isotonic saline or sodium bicarbonate solution is commonly employed, particularly in high-risk patients. The optimal hydration protocol and choice of fluid remain areas of ongoing research, with recent evidence suggesting that sodium bicarbonate may offer advantages over saline in certain populations. Encouraging oral fluid intake in the days leading up to and following the procedure can complement intravenous hydration and contribute to overall fluid balance. The choice of contrast media can significantly influence the risk of CIN. Low-osmolar or iso-osmolar contrast media are generally preferred over high-osmolar contrast media due to their lower nephrotoxicity. Iso-osmolar contrast media, in particular, have demonstrated promising results in reducing CIN incidence in high-risk patients. Minimizing contrast volume is a critical aspect of CIN prevention. This involves a meticulous approach to angiography, employing techniques to reduce contrast exposure while ensuring adequate visualization of the coronary arteries. Utilizing the lowest possible radiation dose and contrast volume necessary to obtain diagnostic images. This may involve adjusting imaging parameters, such as frame rate and acquisition time, and employing techniques like image stitching to reduce the number of injections required. Employing smaller catheters can reduce the volume of contrast media needed for angiography. This requires careful selection of catheters based on patient anatomy and procedural requirements. Careful planning of the procedure and judicious use of contrast injections can minimize unnecessary exposure. This includes avoiding repeat injections unless absolutely necessary and utilizing alternative imaging modalities, such as intravascular ultrasound (IVUS) or fractional flow reserve (FFR), to guide decision-making. Temporarily discontinuing nephrotoxic medications, such as nonsteroidal anti-inflammatory drugs (NSAIDs) and ACEIs/ARBs, before and after the procedure can be a prudent measure in high-risk patients. These medications can impair renal function and exacerbate the nephrotoxic effects of contrast media. The duration of medication withdrawal should be individualized based on the patient's renal function, the specific medication, and the perceived risk of CIN. Close communication with the patient's primary care physician or nephrologist is essential to ensure safe and appropriate medication management. Close monitoring of renal function after the procedure, especially in high-risk patients, is paramount for early detection and management of CIN. Obtaining serum creatinine levels at baseline, 24 hours, and 48-72 hours after the procedure. Assessing urine output as an indicator of renal perfusion and function. Promptly identifying and addressing any signs or symptoms of CIN, such as decreased urine output, fluid retention, or electrolyte imbalances. In addition to these established preventive strategies, ongoing research is exploring novel approaches for preventing and treating CIN. Investigating new biomarkers, such as cystatin C, neutrophil gelatinase-associated lipocalin (NGAL), and kidney injury molecule-1 (KIM-1), for early detection of kidney injury

and risk stratification. Developing more effective hydration protocols, including the use of novel fluids and individualized hydration strategies based on patient characteristics and risk factors. Evaluating the efficacy of pharmacological interventions, such as N-acetylcysteine, sodium bicarbonate, and statins, in preventing CIN. These emerging therapies hold promise for further reducing the incidence and severity of CIN in the future. Effective CIN prevention requires a collaborative approach involving the cardiologist, radiologist, nephrologist, nursing staff, and the patient. Clear communication, shared decision-making, and meticulous attention to detail are essential for optimizing patient outcomes. Educating patients about CIN, its risk factors, and preventive strategies empowers them to actively participate in their care and adhere to recommendations. Close collaboration between healthcare professionals ensures comprehensive risk assessment, individualized preventive strategies, and prompt management of complications.[19,20]

4. Conclusion

This multicenter study in Taiwan identified several independent predictors of contrast-induced nephropathy (CIN) in patients undergoing elective coronary angiography. Chronic kidney disease, diabetes mellitus, anemia, advanced age, increased contrast volume, and reduced left ventricular ejection fraction were all significantly associated with an increased risk of CIN. These findings underscore the importance of meticulous risk assessment and the implementation of targeted preventive strategies, such as adequate hydration, minimizing contrast volume, and careful selection of contrast media, to mitigate the risk of CIN in this patient population. Further research is needed to refine risk stratification, optimize preventive measures, and explore novel therapeutic interventions to minimize the occurrence of CIN and improve patient outcomes.

5. References

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